Technology Introduction

A Study of Vehicle Control Technology Using Image Processing

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1 Introduction

In recent years, research to promote the practical use of the autonomous operation of automobiles, construction equipment, farming equipment, etc., has been active. As represented by the autonomous operation of automobiles, not only mother machine manufacturers but also many different industries, including IT companies, have entered the market. Research to automate machine operation, for which we used to depend on people, is being promoted by utilizing sophisticated intelligence. KYB also needs to start proposing systems among our various products to mother machine manufacturers to follow this flow of automation and intelligence. More relatively inexpensive cameras are starting to be used for autonomous operation, and image processing technologies to recognize the surrounding environment based on camera images are becoming increasingly more important.

Therefore, we decided to focus our research on the automobile auto-parking system, which operates in limited environments while possessing factors of autonomous operation, in order to master the surrounding environment recognition technology and the vehicle control technology, which are element technologies in autonomous operation, and technology to configure them as a system. In our research, we utilized the white line control system, which uses cameras to recognize white line markers, in order to master the autonomous operation technology with the focus on image-processing technology. In this article, I would like to introduce the vehicle control technology using image processing.

2 System Overview

2.1 How auto-parking by white line control works

Fig. 1 shows the flow of entry/parking/exit in auto-parking by white line control. The cameras on the vehicle recognize the white line control markers, which are installed in the parking lot. The vehicle autonomously drives to enter/exit the lot by following the instructions indicated by the marker. Fig. 2 shows an example of markers defined in the white line control markers. Upon constructing auto-parking functions, we assumed the usage that the driver exits the vehicle at the entrance of the parking lot and instructs the vehicle to enter the lot to autonomously park the vehicle. When the driver wants to ride the vehicle again, the driver instructs the vehicle to exit the lot beforehand so that the vehicle travels to the front of the parking lot.

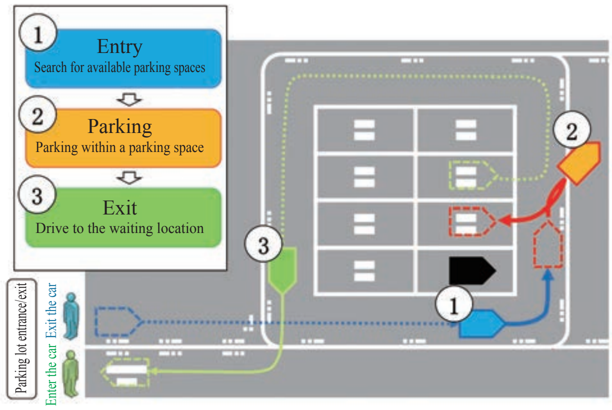

Fig. 1 Auto-parking flow

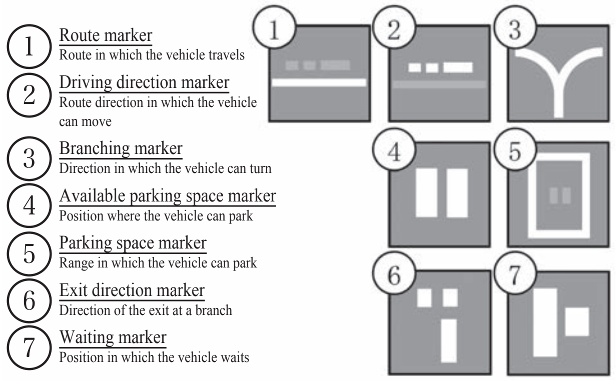

Fig. 2 Marker examples

2.2 Hardware configuration

Fig. 3 shows the hardware configuration. For the base vehicle, we utilized the RoboCar®MV2 Autonomous Driving Package, which is an electric vehicle for research released by ZMP Inc. This base vehicle can control the steering, accelerator, and brake by using CAN signals. On this base vehicle, we installed four monocular cameras that take images of the front/back/sides of the vehicle, an image-processing PC to recognize white line control markers based on the images, and a vehicle control PC that controls operation systems, such as vehicle steering, based on the recognition results.

In this research, we have created the marker recognition program, which recognizes the white line control markers captured by the cameras, and the vehicle control program, which controls the vehicle based on the recognition results. Each PC utilizes an open-sourced OS and image-processing library.

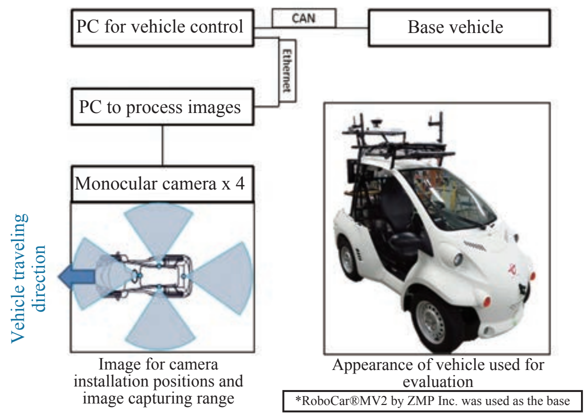

Fig. 3 Hardware configuration

3 How Vehicle Control Works

In vehicle control, the vehicle's target track is generated by the positions/angles/types of various white line control markers, which are recognized periodically. The system calculates commands for steering, accelerator, etc., to follow this target track and control the vehicle by transmitting these commands to the base vehicle via CAN.

Fig. 4 shows the vehicle control flow when the vehicle follows the route. First, it recognizes the positions and angles of route markers, which are captured with the front camera, against the vehicle. It then corrects the horizontal deviation from the route and generates the target track in which the route and vehicle are parallel (① in Fig. 4). When doing so, the target track is generated by calculating the clothoid curve Note 1) that connects the positions and angles of the vehicle at the beginning and end of the drive. The vehicle drives by following this target track and confirms the marker recognition result when it reaches the target point (② in Fig. 4). After this, it continues to follow the route periodically in the timing that markers are recognized (③ and ④ in Fig. 4).

When branching markers are detected, the vehicle generates the track to turn in the available direction based on the branching marker positions/angles and available branching direction information.

Available parking space markers are recognized by cameras on either side of the vehicle. When the marker is recognized, the vehicle shifts to the parking movement. In the parking movement, the vehicle moves to the position in which the available parking space marker can be captured in the back camera. After this, it generates the track by reconfirming the available parking space marker position again with the back camera and parks directly above the available parking space marker.

Note 1) Curve that is approximated as the track followed by a vehicle when the steering wheel of the vehicle, which is driving at a certain speed, is turned at a constant speed.

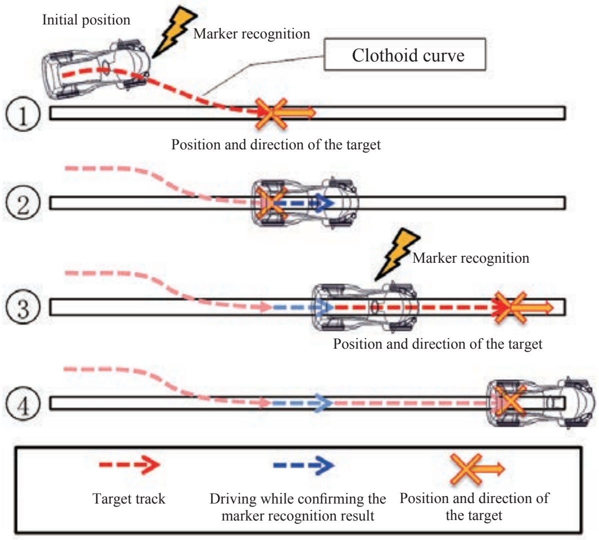

Fig. 4 Flow of driving that follows the route

4 Flow of Image Processing

Fig. 5 shows the flow of image processing in marker recognition. Image processing is mainly divided into three processes – pre-process, main process, and post-process. In response to images obtained from cameras (① in Fig. 5), the pre-process converts the road surface image taken directly above the road into a bird's-eye image (② in Fig. 5) and performs the filtering process (③ in Fig. 5) to extract white lines. The main process detects the outlines of the extracted white lines (④ in Fig. 5) and recognizes white line control markers based on the shapes and positions (⑤ in Fig. 5). The post-process performs tasks, such as converting the recognized marker positions and angles to coordinates (⑥ in Fig. 5).

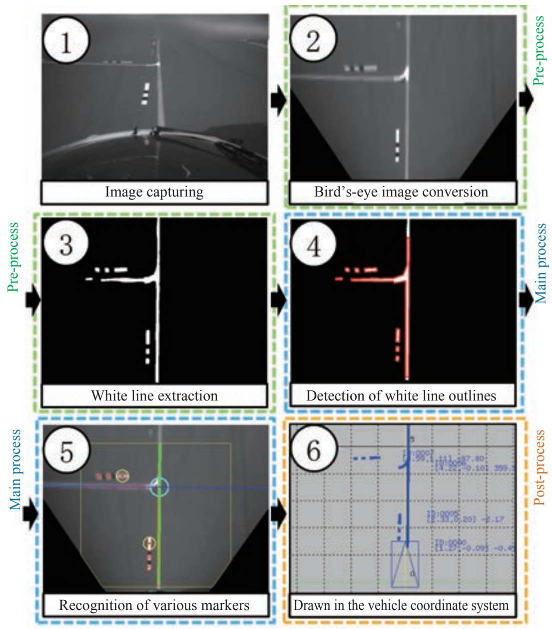

Fig. 5 Flow of image processing with marker recognition

5 Element Technologies in Image Processing

The main process in image processing includes outline detection and recognition of various markers by utilizing a method called “grid template matching” in this review.

5.1 Marker recognition using outline detection

Outline detection is the process to detect the shape/position of a specific segment on the screen. With this process, the white lines are detected and various white line control marker types are recognized.

Fig. 6 shows how white line outlines are detected. First, white lines are extracted through a binarization process to convert the image into two colors: white and black. Next, white line outlines are detected from these white line extraction images. Among the detected outlines, only quadrangles are extracted as candidates for white line control markers. When doing so, outlines that are close to quadrangles are also approximated as quadrangles.

Various marker types are recognized based on the shapes of extracted white line outlines (outline length, length of each side, etc.) and positional relations. Fig. 7 shows the flow to recognize the driving direction markers (markers that define the direction in which the vehicle can move, in relation to the route markers) as an example. Driving direction markers are shaped with three large and small rectangles in a row. The system searches white lines with the same positioning as these shapes from the screen. If the conditions match, the white lines are recognized as driving direction markers.

Route markers are recognized by detecting a thin and long white line that extends from the bottom edge of the screen.

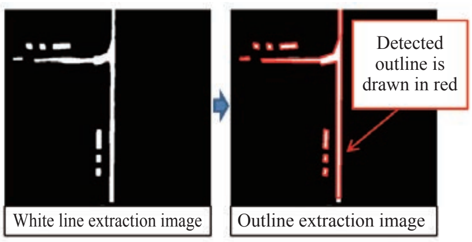

Fig. 6 Outline detection of white lines within images

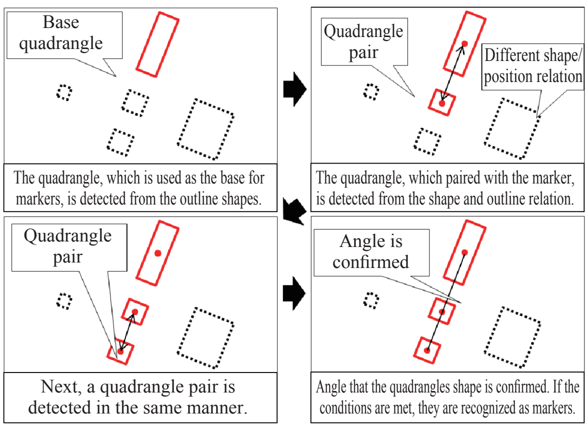

Fig. 7 Process in which markers are recognized from outlines

5.2 Branching marker recognition through grid template matching

Branching markers are shaped uniquely with curves. Vehicles can move forward in the direction that is smoothly connected with a curve or straight line from the entry direction. Vehicles must recognize the characteristics of these unique shapes. Therefore, we are using a system called “grid sensor” that divides markers into nine segments as shown as ① - ⑨ in Fig. 8. In order for the vehicle to easily capture the white line, which runs in the middle of branching markers, and curves that branch out from the white line, the grid sensor divides segments so that the center is narrow and the sides are wide. In addition, by limiting the branching marker candidates with prior conditions of whether or not there is a white line inside of the segment (shown in Fig. 8), we reduce the erroneous recognition rate and process load for pattern matching.

The vehicle detects branching markers and recognizes the branch types by using this grid sensor to search the screen and perform the matching process to determine whether or not there is a white line in each segment, as shown in Fig. 9.

In addition, the system efficiently performs search and simultaneously reduces erroneous recognition when searching for branching markers on the screen with the grid sensor by performing the search along the route markers, which were recognized in the aforementioned outline detection.

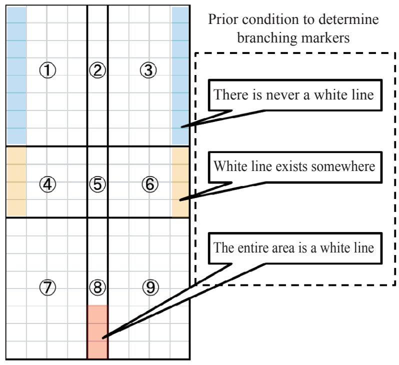

Fig. 8 Grid sensor

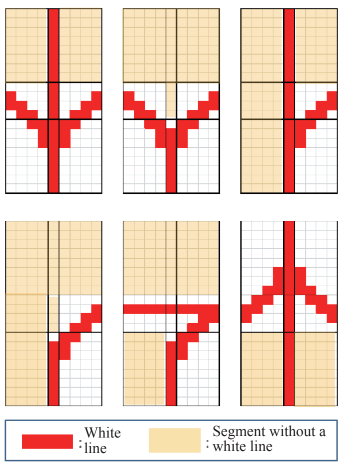

Fig. 9 Branching marker pattern examples

6 Experiment Result

In order to confirm the auto-parking functions, we conducted a demonstrative evaluation by installing a simulated parking lot in our test course. Fig. 10 shows the rough appearance of the installed simulated parking lot. Fig. 11 shows scenes from the experiment in the simulated parking lot.

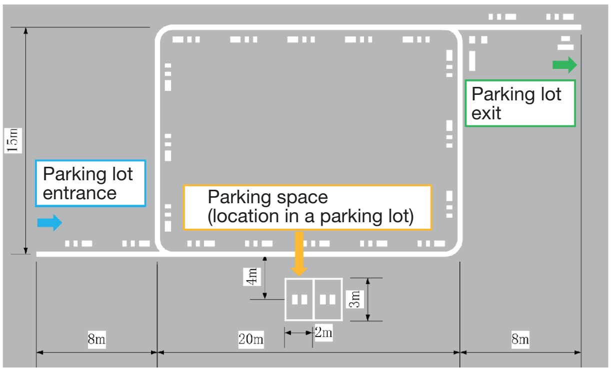

Fig. 10 Overview of the simulated parking lot

Fig. 11 Scenes from the experiment in the simulated parking lot

We confirmed the movements of the vehicle, which searched through the parking lot once after entering the lot, found an available parking space, parked, and drove to the exit after receiving the user's instruction. During the experiment, we made the vehicle move as mentioned above by hiding the available parking space marker when it first passed the parking space and replacing the marker when it passed the space again after driving through the parking lot once. We set the speed at approximately [5km/h] by assuming slow speed to thoroughly ensure safety.

As a result of the evaluation, we confirmed that the vehicle can drive according to the instructions given by the installed white line control markers, enter the parking lot, park, and exit.

The precision to follow the routes was approximately 43 [mm] on average, and the parking position precision was approximately 34 [mm] on average in the lateral direction and 174 [mm] in the longitudinal direction. We have learned that the main reason for the errors in the overall result was vibrations in the vehicle during driving. In addition, we have learned that the error in the longitudinal direction during parking was caused by the fact that we weren't able to reflect the physical characteristics of a vehicle behaving differently when it moves forward and backward on vehicle control.

7 In Closing

In this research, we have established an auto-parking system that uses white line control by utilizing the surrounding environment recognition technology using images and the vehicle control technology, as a first step to proposing systems for sophisticated automation and intelligence. While there are still issues in the recognition precision and vehicle control precision, we were able to confirm that parking is possible by using an actual vehicle in a simulated parking lot.

We can expect that the element technologies of autonomous operation, which we have obtained in this research, will be applicable to not only vehicles but also a wide range of equipment, such as construction equipment and farming equipment. In the future, we plan to apply the findings from the surrounding environment recognition technology using image processing and the vehicle control technology, which we have obtained through the research, to other various products of KYB.

Author

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Joined the company in 2012.
Motion control engineering Sect., Basic Technology R&D Center, Engineering Div.
Mainly engaged in development of image processing technologies involved with operation support.